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(54) **THIN-LAYER SILICON-ON-INSULATOR (SOI) HIGH-VOLTAGE DEVICE STRUCTURE**

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(57) **ABSTRACT**

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

A thin layer SOI high-voltage device in which the drift charge is depleted using a three-dimensional MOS capacitor structure. The drift region of the high-voltage semiconductor device is doped with a graded charge profile which increases from source-to-drain. The drift region is physically patterned to create a stripe geometry where individual SOI stripes. Each SOI stripe is individually circumscribed longitudinally by a dielectric layer wherein each dielectric layer is longitudinally circumscribed by field plates of a conducting multi-capacitor field plate layer which is electrically shorted to the substrate. The resultant structure is a thin drift-region stripe which is completely enclosed by a MOS field plate, resulting in three-dimensional depletion upon application of a bias voltage between the SOI stripe and its encapsulating field plates.

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(51) **Int. Cl.⁷** **H01L 29/94**

(52) **U.S. Cl.** **257/409; 257/347**

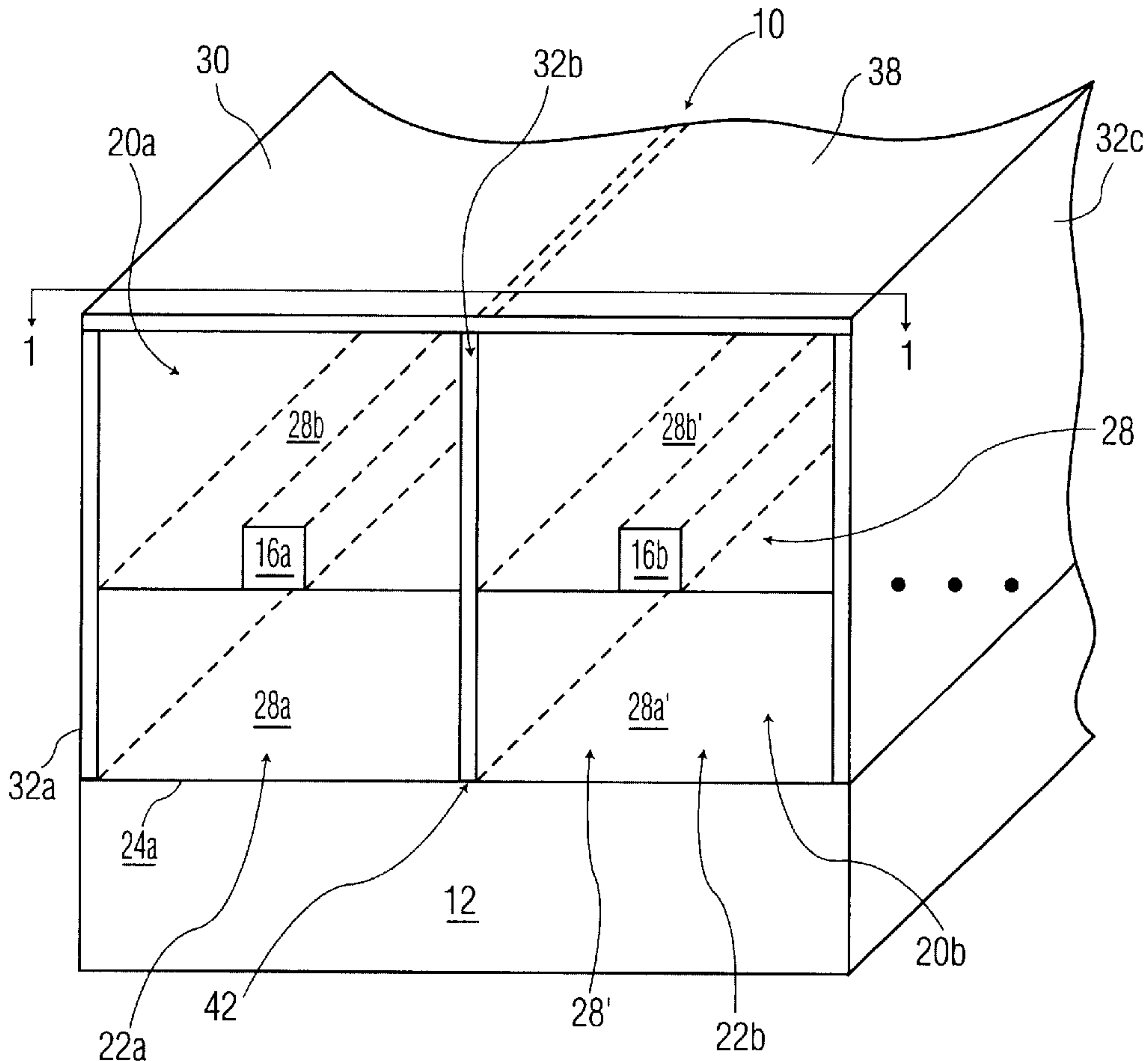
(58) **Field of Search** **257/353, 354, 257/409, 347**

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18 Claims, 5 Drawing Sheets



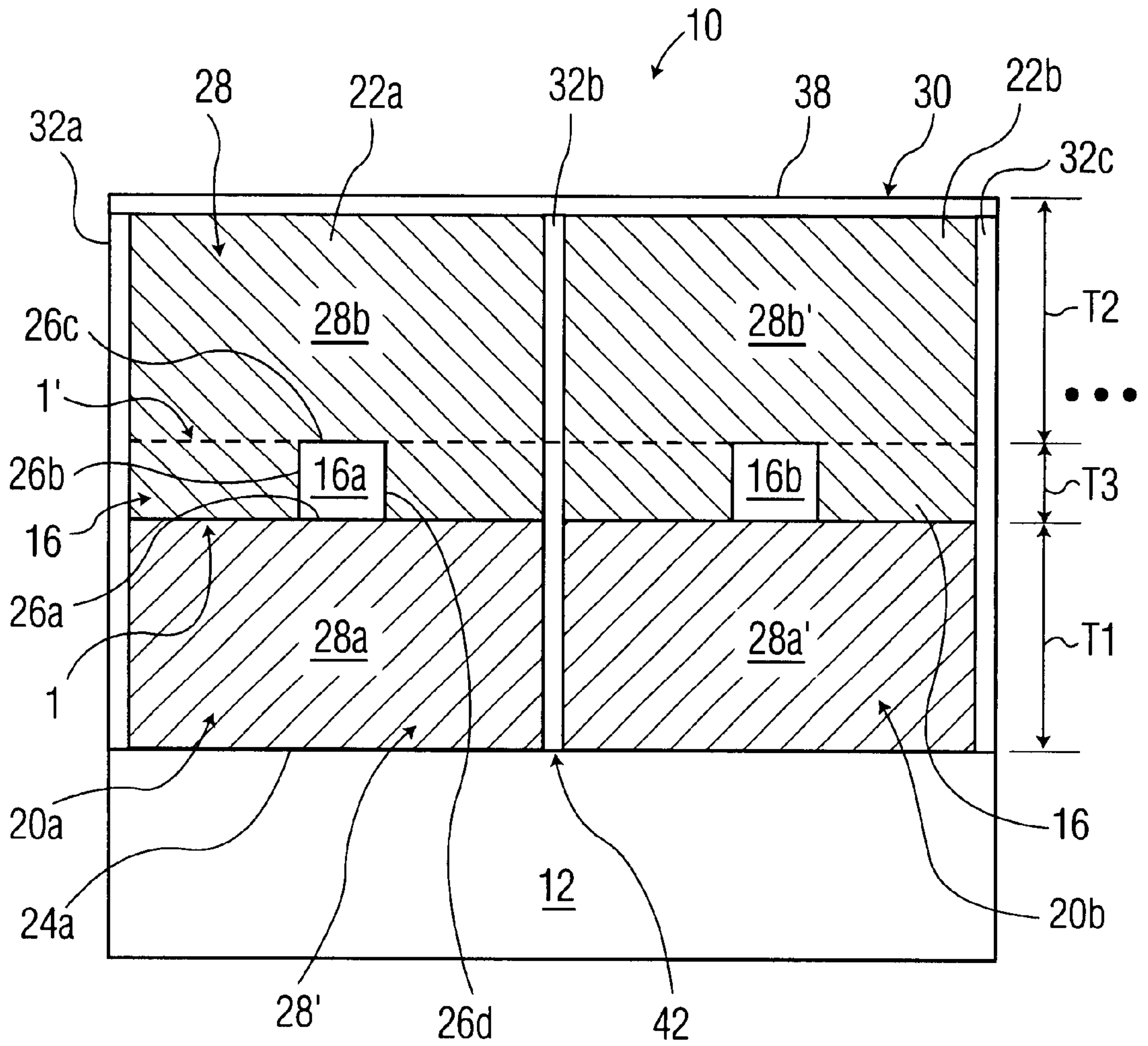


FIG. 2

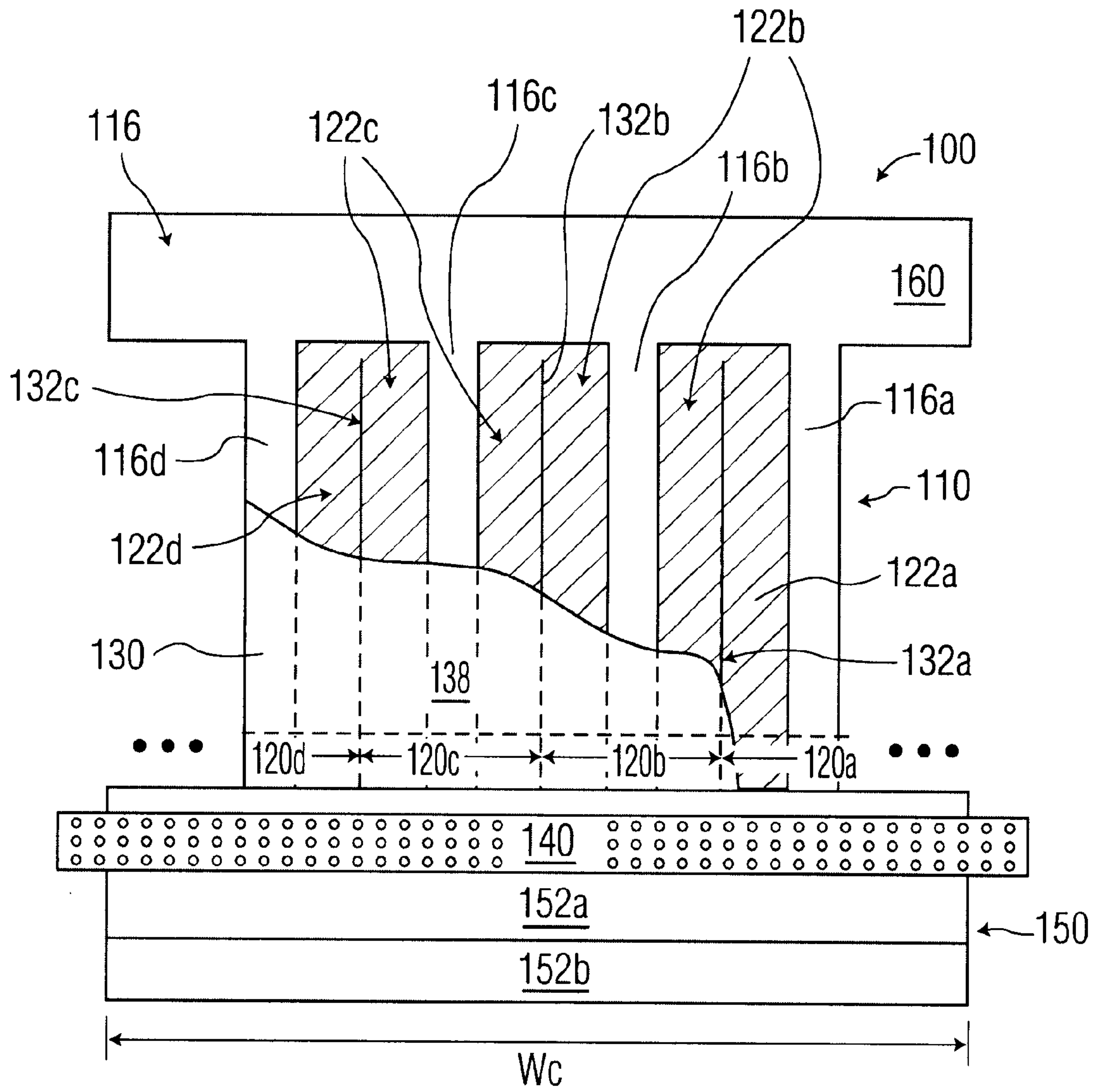


FIG. 3A

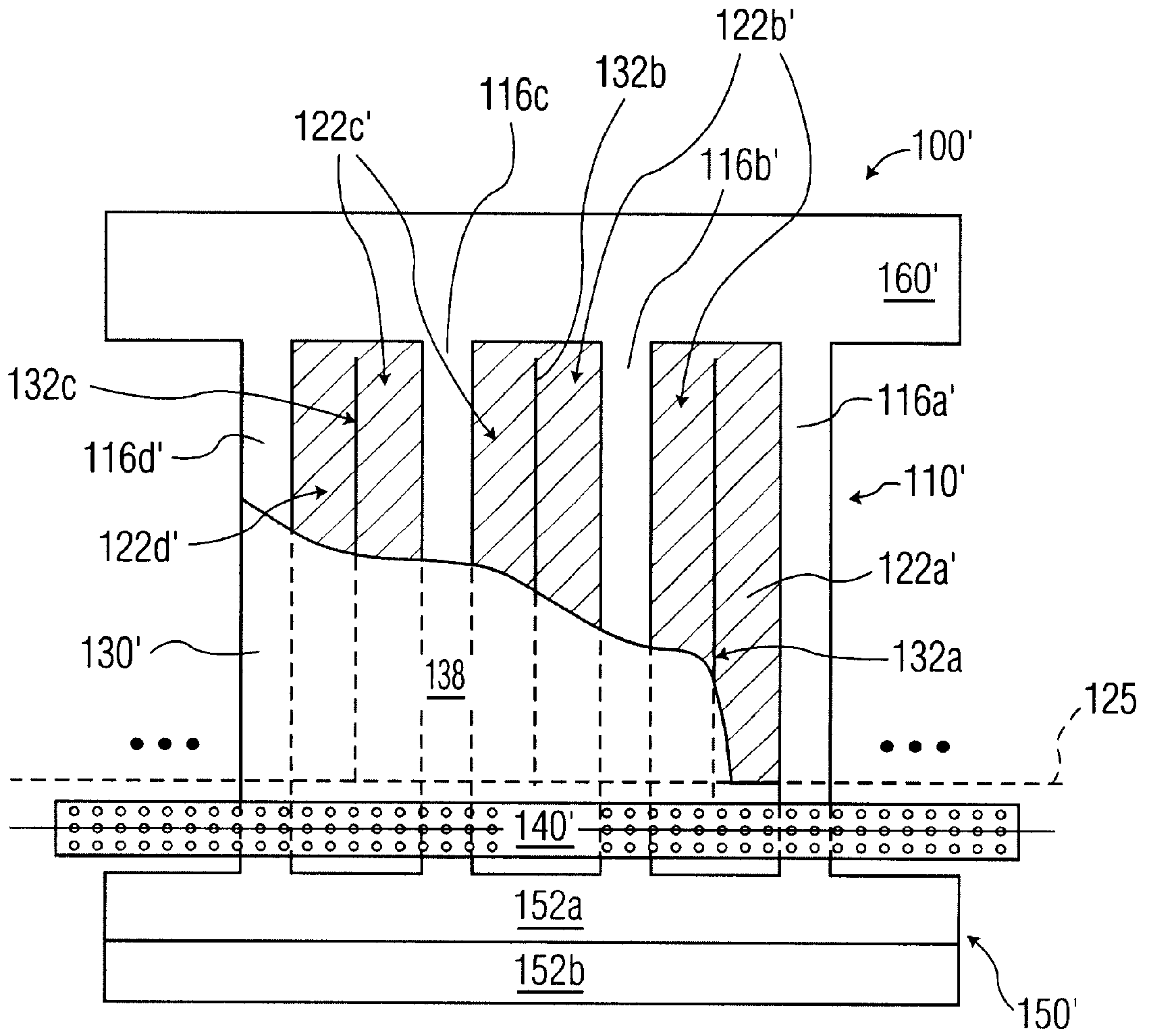


FIG. 3B

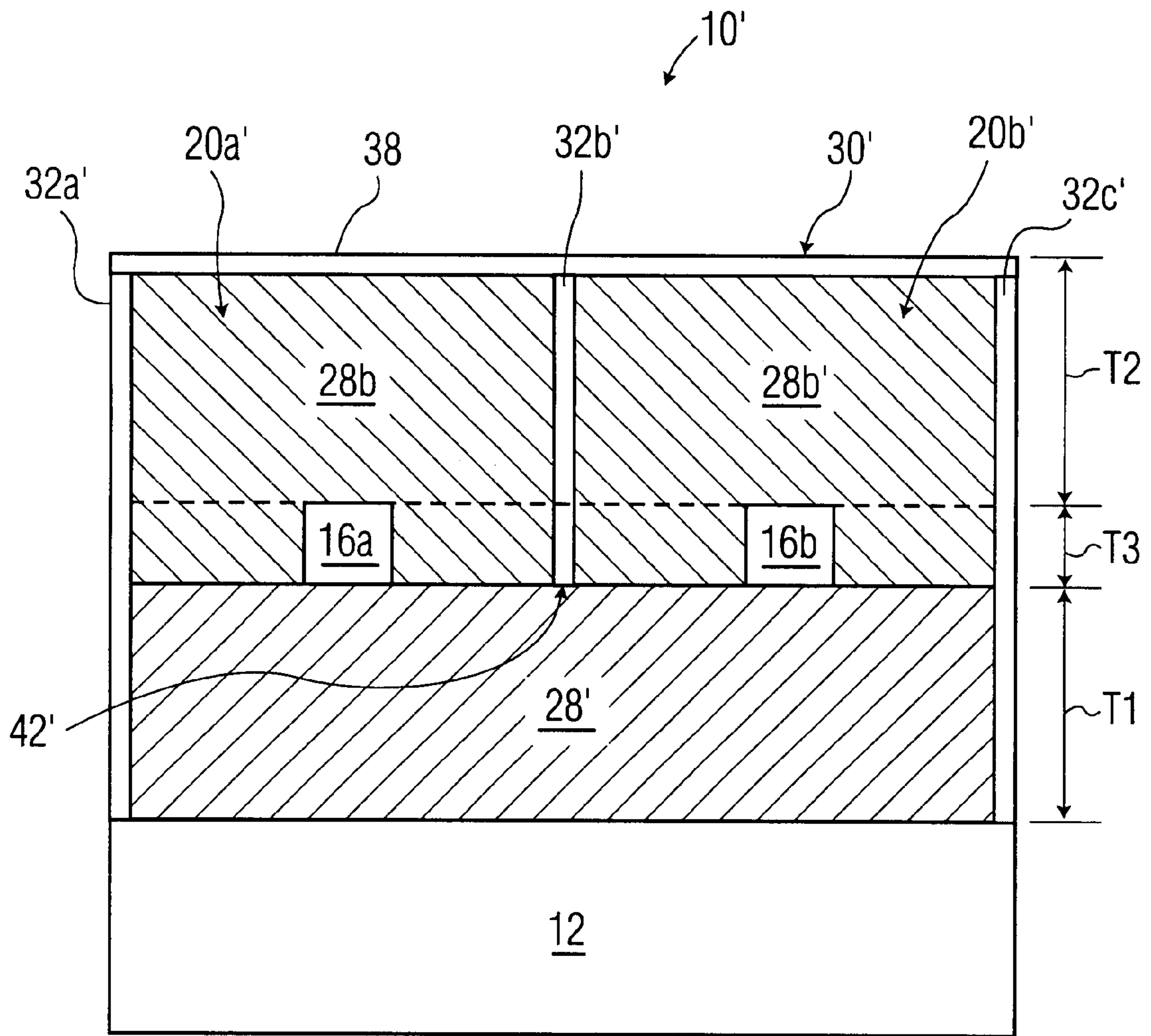


FIG. 4

THIN-LAYER SILICON-ON-INSULATOR (SOD) HIGH-VOLTAGE DEVICE STRUCTURE

FIELD OF THE INVENTION

This invention relates to semiconductor devices, and more particularly to a thin-layer silicon-on-insulator (SOD) high-voltage device structure which employs multiple three-dimensional metal-oxide semiconductor (MOS) capacitor structures to achieve multi-dimensional depletion of the drift charge to improve the breakdown-voltage specific “on” resistance figure-of-merit across a wide range of application voltages.

BACKGROUND OF THE INVENTION

There has been various SOI high voltage device structures in which a field plate construction and drift region doping are used to improve the breakdown voltage specific “on” resistance figure-of-merit. Improved “on” resistance for low voltage application has been obtained using trench device structures in bulk silicon technology. Other thin-layer high voltage devices have improved current driving capability.

Recently, multi-dimensional depletion in the drift region has been achieved by inserting shaped PN-junctions into the graded-doped drift region of the device. Thus, the device could support high voltages with higher levels of charge in the drift region, without extensive thermal oxidation process steps. However, there is an alternative structure in which a MOS dielectric can be used to support higher sustainable electric fields. Such a construction can be used to improve the breakdown voltage specific “on” resistance figure-of-merit.

SUMMARY OF THE INVENTION

The present invention contemplates a thin-layer silicon-on-insulator (SOI) high voltage device comprising a semiconductor substrate and a three-dimensional MOS multi-capacitor structure which forms a depletable drift region. The three-dimensional MOS multi-capacitor structure includes a striped geometry of parallel thin, SOI stripes, wherein each SOI stripe is individually circumscribed longitudinally by a respective dielectric layer formed on the semiconductor substrate, and a conducting multi-capacitor field plate layer superimposed on top of the respective dielectric layer and between adjacent dielectric layers circumscribing longitudinally adjacent SOI stripes.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a three-dimensional MOS multi-capacitor structure of a drift region of the present invention.

FIG. 2 illustrates a cross sectional view along the plane 1—1 of the embodiment of FIG. 1.

FIG. 3A illustrates a top view of a lateral diffused metal-oxide semiconductor (LDMOS) device structure of the present invention employing the three-dimensional MOS multi-capacitor structure of FIG. 1.

FIG. 3B illustrates an alternative embodiment of the top view of an LDMOS device structure of the present invention employing the three-dimensional MOS multi-capacitor structure of FIG. 1.

FIG. 4 illustrates an alternate embodiment of the three-dimensional MOS multi-capacitor structure of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to FIG. 3A, an alternate way to achieve multi-dimensional depletion in a thin-layer SOI device **100**,

such as without limitation, a LDMOS device, is to insert a MOS field plate multi-capacitor structure **110** in the drift region which is biased to deplete the drift charge. This has the same effect on the device’s performance as in the prior art, namely providing a higher level of doping in the drift region for a specified breakdown voltage. The MOS field plate multi-capacitor structure **110** has a benefit over the PN-junction depletion method in that the MOS dielectric can support higher electric field strengths prior to breakdown. This means that (ideally) the MOS field plate multi-capacitor scheme would have a better breakdown voltage specific “on” resistance figure-of-merit.

Referring now to FIGS. 1 and 2, an exemplary MOS field plate multi-capacitor structure **10** will be described in detail below. The exemplary MOS field plate multi-capacitor structure **10** as shown includes two parallel and juxtaposed MOS capacitors **20a** and **20b**. However, any number of parallel and juxtaposed MOS capacitors can be provided. The MOS field plate multi-capacitor structure **110** of FIG. 3A includes more than two MOS capacitors, as will be described in more detail later.

The MOS field plate multi-capacitor structure **10** includes a plurality of SOI stripes **16a** and **16b**, each of which is individually encapsulated, sealed or circumscribed longitudinally by dielectric layers **22a** and **22b**, respectively, disposed on a semiconductor substrate **12**, such as, without limitation, a silicon substrate. The semiconductor substrate **12** may have either a N-type conductivity or a P-type conductivity.

The dielectric layer **22a** has a bottom periphery surface **24a** disposed on the semiconductor substrate **12** and its interior periphery surfaces **26a**, **26b**, **26c** and **26d** circumscribing the top, bottom and longitudinal exterior periphery surfaces of the SOI stripe **16a**. Likewise, dielectric layer **22b** circumscribes the SOI stripe **16b**. In the exemplary embodiment, the dielectric layers **22a** and **22b** are made of silicon dioxide, also referred to as “oxide.” However, any dielectric with a low dielectric constant could be used.

The dielectric layer **22a** is comprised of a buried insulating layer **28a** having the SOI stripe **16a** disposed thereon and a top insulating layer **28b** disposed over the top of and longitudinally along the SOI stripe **16a**. The SOI stripe **16a** is in the form of a geometrically-shaped stripe or strip having a width which is shorter than the width of the buried insulating layer **28a** and the top insulating layer **28b**. The thicknesses of the SOI stripe **16a**, the buried insulating layer **28a** and the top insulating layer **28b** will be described below in relation to the fabrication process. Since SOI stripe **16a** has a shorter width than the buried insulating layer **28a** and the top insulating layer **28b**, the top and side periphery surfaces of the SOI stripe **16a** are longitudinally circumscribed by the top insulating layer **28b** while the bottom surface is interfaced by the buried insulating layer **28a**. Likewise, dielectric layer **22b** is comprised of buried insulating layer **28a'** and top insulating layer **28b'**.

The MOS field plate multi-capacitor structure **10** further includes a conducting multi-capacitor field plate layer **30** superimposed longitudinally on top of the dielectric layers **22a** and **22b** and between the adjacent dielectric layers **22a** and **22b** circumscribing longitudinally adjacent SOI stripes **16a** and **16b**.

More specifically, the conducting multi-capacitor field plate layer **30** includes a plurality of longitudinal dividing field plates **32a**, **32b** and **32c** and a top longitudinal field plate **38**. As can be appreciated, in this exemplary embodiment, field plate **32b** is shown dividing SOI stripe

16a and **16b** and their respective dielectric layers **22a** and **22b**, respectively. However, field plates **32a**, and **32c** would also divide other adjacent dielectric layers, as will be described in more detail with respect to FIGS. **3A** and **3B**. Moreover, the number of longitudinal dividing field plates is dependent on the number of SOI stripes.

The length of the plurality of longitudinal dividing field plates **32a**, **32b** and **32c** is slightly shorter than the length of the dielectric layers **22a** and **22b**. Thus, the end edges of the plurality of longitudinal dividing field plates **32a**, **32b** and **32c** are layered with dielectric which may be part of dielectric layer **22a** and/or dielectric layer **22b**, as best seen in FIG. **3A**.

In view of the foregoing, it can be readily seen that the MOS field plate multi-capacitor structure **10** includes MOS capacitor **20a**, which is embodied by the longitudinal dividing field plates **32a** and **32b**, SOI stripe **16a** and dielectric layer **22a**, and MOS capacitor **20b**, which is embodied by the longitudinal dividing field plates **32b** and **32c**, SOI stripe **16b** and dielectric layer **22b**. Furthermore, since the MOS capacitors **20a** and **20b** are juxtaposed the common field plate, namely, the top longitudinal field plate **38** is shared thereby. The field plates **32a**, **32b**, **32c** and **38** are made of a metallic or a polysilicon material.

In the embodiment of FIGS. **1** and **2**, the longitudinal dividing field plates **32a**, **32b**, and **32c** extend down to the semiconductor substrate **12** in via (route) **42** and is electrically shorted to the semiconductor substrate **12**. In general there is an ohmic connection between the longitudinal dividing field plates **32a**, **32b**, and **32c** extending down to the semiconductor substrate **12**.

In summary, each SOI stripe **16a** and **16b** is completely enclosed longitudinally by the MOS field plate capacitor **20a** and **20b** defined by sequential deposition of a dielectric and a conducting multi-capacitor field plate layer **30**. In other words, the end exterior periphery surfaces of both the SOI stripes **16a** and **16b** are not bounded by the dielectric layers **22a** and **22b**, respectively, and the conducting multi-capacitor field plate layer **30**. Moreover, in the exemplary embodiment, the end exterior periphery surfaces of the dielectric layers **22a** and **22b** are not bounded by the conducting multi-capacitor field plate layer **30**. In profile, the conducting multi-capacitor field plate layer **30** of a single MOS field plate capacitor **20a** or **20b** has a generally inverted "U"-shaped.

In the exemplary, embodiment, the geometric shape of the SOI stripe **16a** (shown in cross-section in FIG. **2**) does not have to be square or rectangular. Instead, other geometries such as, without limitation, circular or cylindrical geometries are also usable as long as the cross-section of the SOI stripe **16a** and the conducting multi-capacitor field plate layer **30** are of similar, cross-section and are concentrically scaled. In the exemplary embodiment, the thickness **T1** of the buried insulating layer **28a** is substantially the same as the thickness **T2** of the top insulating layer **28b**. The thickness **T3** of the SOI stripe **16a** centers it between the buried insulating layer **28a** and the top insulating layer **28b**. Likewise, the SOI stripe **16b** is centered between the buried insulating layer **28a'** and the top insulating layer **28b'**.

An advantage of the three-dimensional MOS multi-capacitor structure **10** is a higher charge slope in the drift region as compared to the prior art for the same breakdown voltage. While not wishing to be bound by theory, the three-dimensional MOS multi-capacitor structure **10** leads to an improvement in specific "on" resistance and saturated current flow.

The fabrication process of the three-dimensional MOS multi-capacitor structure **10** will now be described in detail below.

Step 1 of the fabrication process includes selecting the thicknesses **T1** and **T3** for the buried insulating layer **28'** and the SOI layer **16** (which includes the area between the solid line **1** and the line **1'** shown in phantom) for a specific application voltage. Initially the SOI layer **16** extends over the buried insulating layer **28'**. In the exemplary embodiment, for a application voltage of 700V, the SOI layer **16** has a 1.0 micron thickness (**T3**) and the buried insulating layer **28'** has a thickness of 3.0 microns (**T1**).

Step 2 of the fabrication process includes doping the SOI layer **16** with a graded charge profile to set a desired monotonic electric field in the drift region.

Step 3 of the fabrication process includes anisotropically etching the SOI layer **16** to form the individual SOI stripes **16a** and **16b** on the top surface (solid line **1**) of the buried insulating layer **28'**.

Step 4 of the fabrication process includes subsequent deposition of the dielectric to form a top insulating layer **28**.

Step 5 of the fabrication process includes etching in the center of the top insulating layer **28** and the buried insulating layer **28'**, between adjacent SOI stripes **16a** and **16b**, a trench-type geometry to create and expose a via (route) **42** to the substrate **12** thereby forming parallel top insulating layers **28b** and **28b'** and parallel buried insulating layers **28a** and **28a'** for MOS capacitors **20a** and **20b**, respectively. As can be appreciated, a via would be created in the top insulating layer **28** and the buried insulating layer **28'** between any two adjacent SOI stripes. Thus, vias are created for field plates **32a** and **32c** to extend to substrate **12**.

Step 6 of the fabrication process includes a refill process with a metal or polysilicon to create the conducting multi-capacitor field plate layer **30** which is superimposed on top of the dielectric layers **22a** and **22b** and between adjacent dielectric layers **22a** and **22b** which longitudinally circumscribe adjacent SOI stripes **16a** and **16b**.

The conduction electrode (conducting multi-capacitor field plate layer **30**) of the MOS multi-capacitor structure **10** completely encapsulates, longitudinally, the graded-doped SOI stripes **16a** and **16b**, thus depleting the SOI stripes **16a** or **16b** from all sides upon application of a bias voltage.

Step 7 of the fabrication process includes electrically shorting the conducting multi-capacitor field plate layer **30** to the semiconductor substrate **12**.

The resultant structure of the fabrication process is thin drift-region SOI stripes **16a** and **16b** which are completely enclosed longitudinally by a conducting multi-capacitor field plate layer **30**, resulting in three-dimensional depletion upon application of a bias voltage between each individual SOI stripe **16a** and **16b** and the field plates **32a**, **32b**, **32c** and **38** of their individual MOS capacitors **20a** and **20b**, respectively.

The three-dimensional MOS multi-capacitor structure **10** of the present invention is not limited to high voltage applications. Appropriate selection of the dielectric layer thickness **T1** and SOI layer thickness **T3** results in three-dimensional structures which can be used for blocking voltages from 2 to 1000V. In general, the design, as a function of application voltage, involves selecting a maximum electric field strength in the silicon (semiconductor substrate layer **12**) and the dielectric layers.

FIG. **4** illustrates a simpler alternative embodiment for fabricating the MOS field plate multi-capacitor structure **10'**.

The MOS field plate multi-capacitor structure **10'** is similar to the MOS field plate multi-capacitor structure of the embodiment of FIGS. 1 and 2, except that vias are not etched through the buried insulating layer **28'** to the substrate **12**. Instead, the buried insulation layer **28'** is a solid layer and does not have vias etched therethrough.

The MOS field plate multi-capacitor structure **10'** includes MOS capacitors **20a'** and **20b'** which extend to the top surface of the buried insulating layer **28'**. The longitudinal dividing field plates **32a'**, **32b'** and **32c'** extend down to the top surface of the buried insulating layer **28'**. A via (route) **42'** is created through the top insulating layer **28** forming the parallel top insulating layers **28b** and **28b'** down to the buried insulating layer **28'**.

As can be appreciated, the embodiment of FIG. 4 is somewhat easier to construct than the one shown in FIG. 1, since the deposition of the conducting multi-capacitor field plate layer **30'** is not extended to the substrate **12**. In this embodiment, there is a metal-to-dielectric or insulator connection between the conducting multi-capacitor field plate layer **30'** and the buried insulating layer **28'**.

Referring now to FIG. 3A, a top view of the thin-layer SOI device **100**, is shown. In the exemplary embodiment, the thin-layer SOI device **100** is a lateral double-diffused metal-oxide semiconductor (LDMOS) device. Hence, the description herein will be related to the structure of the LDMOS device which is a metal-oxide semiconductor field effect transistor (MOSFET). The LDMOS device includes a three-dimensional MOS multi-capacitor structures **110**. The three-dimensional MOS multi-capacitor structure **110** is essentially the same as the three-dimensional MOS multi-capacitor structure **10** shown in FIGS. 1 and 2, except that it includes SOI stripes **116a**, **116b**, **116c**, and **116d** and MOS capacitors **120a**, **120b**, **120c** and **120d** (MOS capacitors **120a** and **120d** shown in part). Furthermore, the top longitudinal field plate **138** of the conducting multi-capacitor field plate layer **130** is partially shown and the dielectric layers **122a**, **122b**, **122c** and **122d** are shown cross-hatched and removed over the longitudinal top periphery surface of the SOI stripes **116a**, **116b**, **116c** and **116d** for clarity.

The LDMOS device includes an SOI layer **116** which extends from drain **160** to source **150** from which the SOI stripes **116a**, **116b**, **116c**, and **116d**. The overall contour of the top view of the SOI layer **116** is an "I"-beam configuration. The drain **160** is a shallow N layer which extends along the width W_c of the channel and is also elongated in a plane perpendicular to the longitudinal dividing field plates **132a**, **132b**, **132c** at one end of the SOI stripes **116a**, **116b**, **116c**, and **116d**.

The LDMOS device further includes a polysilicon gate **140** which is disposed at the other end of the three-dimensional MOS multi-capacitor structure **110** and is elongated in a plane perpendicular to the longitudinal dividing field plates **132a**, **132b**, **132c**. The source **150** is formed by a first shallow N layer **152a** and a second shallow P layer **152b**, both of which have a width which is substantially the width W_c of the channel. In this embodiment, the a polysilicon gate **140**, a polysilicon stripe is deposited over an un-etched or unpatterned portion of the SOI layer **116**.

In the exemplary embodiment, standard self-aligned process modules (drain **160** and source **150**) are used to form the active channel of the LDMOS device, diffusing a dopant under a self-aligned polysilicon stripe forming the polysilicon gate **140**. In the embodiment of FIG. 3A, the three-dimensional MOS multi-capacitor structure **110** is confined to the drift region of the LDMOS device. Furthermore, the LDMOS device is self-terminated in a conventional manner.

As can be appreciated, the thin-layer SOI device **100** is not only limited to MOSFET active devices. Instead other semiconductor devices, such as, without limitation, JFETs, bipolar, merged MOS/bipolar, etc., can be fabricated with this high voltage handling drift region, described herein.

Referring now to FIG. 3B, in an alternate embodiment of the thin-layer SOI device **100'**, the three-dimensional MOS multi-capacitor structure **110'** extends from the drain **160'** under the polysilicon gate **140'** to source **150'**. The SOI layer **116'** extends through the drain **160'** and the source **150'**. The polysilicon gate **140'** is deposited over the etched SOI stripes **116a'**, **116b'**, **116c'**, and **116d'**. Dotted line **125** indicates the end of the dielectric layers **122a'**, **122b'**, **122c'** and **122d'**, and the conducting multi-capacitor field plate layer **130**.

The embodiment of FIG. 3B, such an arrangement has the benefit of higher channel periphery, as the polysilicon (PS) gate electrode is deposited conformally over patterned SOI stripes **116a'**, **116b'**, **116c'**, and **116d'** giving sidewall contributions (sidewalls shown in phantom) to channel current. This arrangement is particularly advantageous for a lateral high-voltage device structure.

Referring still to FIG. 3B, the arrangement of the device **100'** or the LSMOS device provides for a lower "on" resistance and the channel periphery is doubled as the polysilicon gate **140'** is deposited conformally over the patterned SOI stripes **116a'**, **116b'**, **116c'** and **116d'** which extend beyond the three-dimensional MOS multi-capacitor structure **110'**. Moreover, the channel conductivity is dropped by a factor of two (2).

In view of the foregoing, the three-dimensional MOS multi-capacitor structures **110** and **110'** of the embodiments of FIGS. 3A and 3B may be designed in accordance with the details of either FIG. 1 or FIG. 4.

Numerous modifications to and alternative embodiments of the present invention will be apparent to those skilled in the art in view of the foregoing description. Accordingly, this description is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the best mode of carrying out the invention. Details of the structure may be varied substantially without departing from the spirit of the invention and the exclusive use of all modifications which come within the scope of the appended claims is reserved.

What is claimed is:

1. A thin-layer silicon-on-insulator (SOI) device comprising:

- a semiconductor substrate;
- a three-dimensional metal-oxide semiconductor (MOS) multi-capacitor structure formed on the substrate, wherein the MOS forms a drift region patterned by a striped geometry of thin, silicon-on-insulator (SOI) stripes and each SOI stripe includes a respective dielectric layer disposed on the semiconductor substrate and;
- a conducting field plate layer superimposed on top of the respective dielectric layer and between adjacent dielectric layers.

2. The device according to claim 1, wherein each of the dielectric layers includes a buried insulating layer interfacing a bottom periphery surface of a respective SOI stripe, and a top insulating layer interfacing remaining periphery surfaces of the respective SOI stripe.

3. The device according to claim 2, wherein the buried insulating layer has a first thickness, each SOI stripe has a second thickness, and the first thickness and the second thickness are for a specific application voltage.

4. The device according to claim 3, wherein each SOI stripe is substantially in a center of the respective dielectric layer.

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5. The device according to claim 1, wherein the conducting field plate layer is electrically shorted to the semiconductor substrate.

6. The device according to claim 1, further comprising:
a silicon-on-insulator layer extending from a drain to a source from which the silicon-on-insulator (SOI) stripes are formed; and,

a gate coupled across one end of the three-dimensional MOS multi-capacitor structures and over an unpatterned portion of the silicon-on-insulator layer.

7. The device according to claim 1, further comprising:
a silicon-on-insulator layer extending from a drain to a source from which the silicon-on-insulator (SOI) stripes are formed; and,

a gate coupled over the silicon-on-insulator (SOI) stripes extending beyond the three-dimensional MOS multi-capacitor structure.

8. The device according to claim 7, wherein the drain is comprised of a shallow N layer which extends along the width a channel, and the source is comprised of a shallow N layer and a shallow P layer.

9. A thin-layer silicon-on-insulator (SOI) device comprising:

a silicon-on-insulator (SOI) layer extending from a drain to a source;

a three-dimensional metal-oxide semiconductor (MOS) field plate multi-capacitor structure forming a drift region patterned by a striped geometry of thin, SOI stripes of the SOI layer and biased to deplete a drift charge to achieve multi-dimensional depletion.

10. The device according to claim 9, wherein each SOI stripe includes a respective dielectric layer disposed on a semiconductor substrate, and a conducting field plate layer superimposed on top of the respective dielectric layer.

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11. The device according to claim 10, wherein each of the dielectric layers includes:

a buried insulating layer interfacing a bottom periphery surface of a respective SOI stripe; and

a top insulating layer interfacing remaining periphery surfaces of the respective SOI stripe.

12. The device according to claim 11, wherein the buried insulating layer has a first thickness, each SOI stripe has a second thickness, and the first thickness and the second thickness are adapted for a specific application voltage.

13. The device according to claim 12, wherein each SOI stripe is substantially in a center of the respective dielectric layer.

14. The device according to claim 11, wherein the conducting field plate layer extends down to and is electrically shorted to the semiconductor substrate.

15. The device according to claim 11, wherein the conducting field plate layer extends down to the buried insulating layer.

16. The device according to claim 9, wherein the drain is comprised of a shallow N layer which extends along the width a channel, and the source is comprised of a shallow N layer and a shallow P layer.

17. The device according to claim 9, further comprising:

a gate coupled across one end of the three-dimensional MOS multi-capacitor structures and over an unpatterned portion of the silicon-on-insulator layer.

18. The device according to claim 9, further comprising:

a gate coupled over the silicon-on-insulator (SOI) stripes extending beyond the three-dimensional MOS multi-capacitor structure.

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